

# A New Geological Understanding of Pillar Point Bluff – Including the Formation of Half Moon Bay

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December 2021

Pillar Point and the adjoining bluffs sit on the northern end of Half Moon Bay and have an elevated profile with the Vandenberg Tracking Station “golf ball” on top recognizable to anyone driving along Highway 1 north of the city of Half Moon Bay. The geology of these bluffs had long been thought to be reasonably well understood and mainly related to the San Gregorio Fault forming the eastern scarp of the bluffs. But after many years exploring this area it is concluded the previous understanding is incomplete and significantly incorrect. A companion full report now shows a new fault mapping where the main strike-slip (horizontal movement) fault actually goes up the middle of the bluff and bifurcates on the northern end and the prominent scarp along the eastern side is likely a dip-slip (vertical movement) fault. A more precise method to measure how fast the fault is moving is also proposed in this report. In addition, it is now understood how these bluffs played a part in the formation of Half Moon Bay and the Moss Beach Syncline. The companion report reviews the evidence leading to the above conclusions plus several other findings. It is very long and detailed and likely not for the faint of heart, so this short summary of some of the main findings has been added. That full report is being put on-line as a reference at the end of this summary report. It hasn’t been published in a peer reviewed journal as yet, that will likely take some time.

Over the many years I hiked along these bluffs on my way to a new fault exposure site or taking geophysical measurements, I would often get questions from passersby, who I would usually recognize by sight or by the sight of their dogs, “What are you looking for?” “Geologic Faults” was my usual reply. Then I’d receive the usual quizzical look. “I can help you with that. You need to go over to the east side by the airport.” Everyone knew where the San Gregorio Fault was (called the Seal Cove Fault in this area), it was along the steep rise on the side of Pillar Point Bluff facing the Half Moon Bay Airport. If I was a geologist, why wouldn’t I already know that? Everybody in the Seal Cove area of Moss Beach knew it well. On the north end, in the residential area, the bluff edge dissipated, and the fault became more scattered, but where the scarp was prominent along the east side of the bluff it was certain. I would explain, and the companion report presents in detail, the new evidence leading me to the new conclusions. I could tell they didn’t always accept that. Indeed, most geologists once agreed with them, and I can’t say I have convinced all of them to change their minds either.

I have a PhD in Physics, had a career in the high-tech field, and then took up geology as a pastime after retirement when I took geology classes at San Jose State U and joined Prof. Kim Blisniuk’s research group meetings where I presented a lot of what is in this report, and have collaborated with her and others on this who are listed in the Acknowledgements section of the report and will be involved in putting my work in context with theirs for a publication. From my frequent enjoyable discussions with the area’s residents, I find there is keen interest in the

geology of the bluffs and this is largely for them. I am not a degreed geologist and until the USGS or CGS (California Geological Society) incorporates their version of these results in their maps my findings and interpretations should be considered tentative.

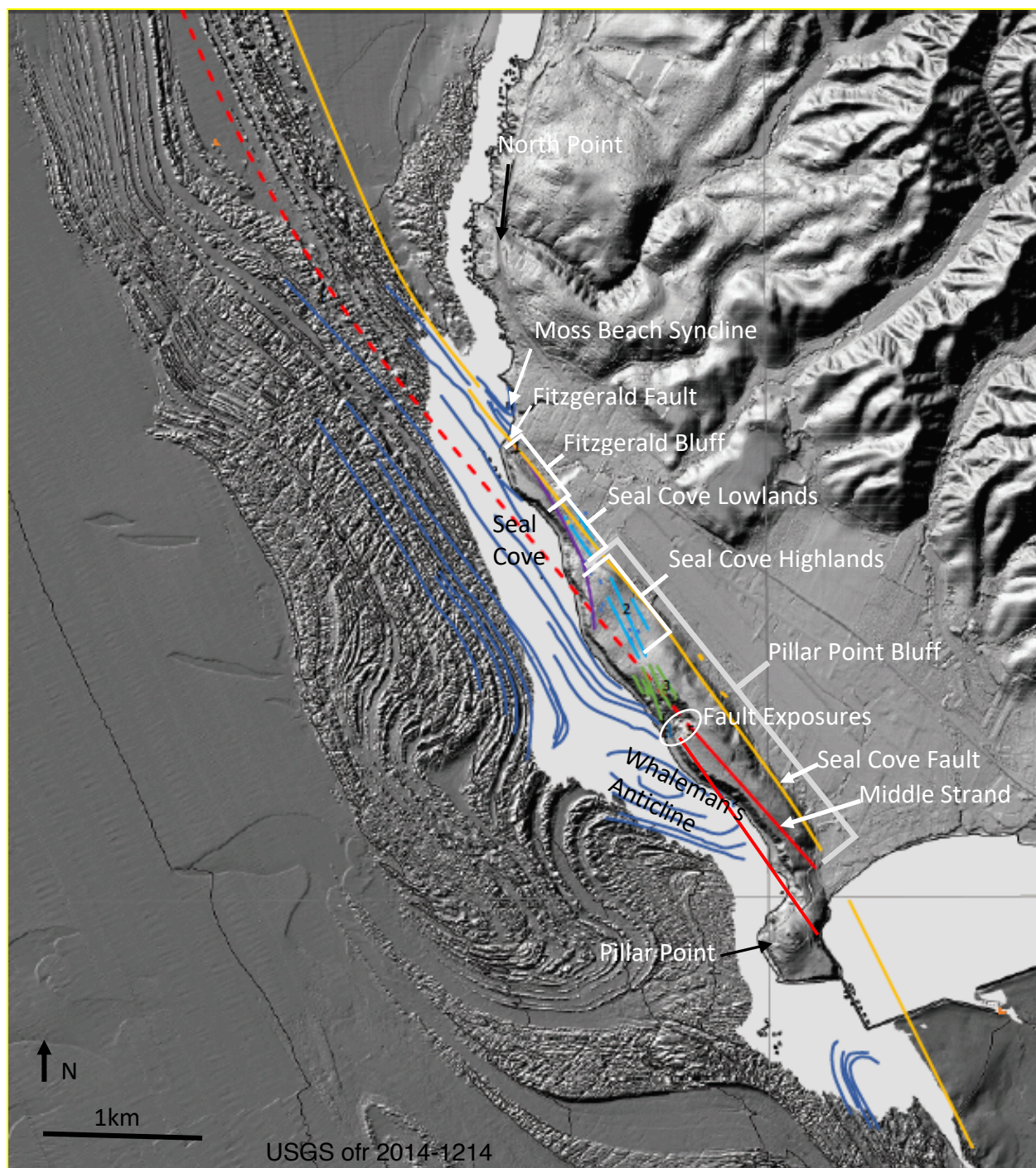


Figure 1: (2) Bathymetry map offshore and lidar of on-land area of Pillar Point Bluff with identifications used in this report added. The Seal Cove Fault, in gold, follows the current Alquist-Priolo mapping part of which is disputed in this report, see Figure (2) of full report for detailed explanation. (In this summary, figure numbers from the attached full report are included in parenthesis in the figure captions.)



*Figure 2: (5) Fitzgerald Fault exposure. T. Wiley Photo 1984, looking SE. Marine terrace deposit on left against Purisima mudrock on right, slickensides plunge reported as 10° SE. This exposure is currently covered by rip rap.*

## Geologic Setting:

Pillar Point Bluff is a marine terrace similar in many ways to other terraces along the California coast. It is underlain by a bedrock layer that was leveled off by sea erosion to form a wavecut platform. Then the sea receded leaving the bedrock covered by beach sand. The bedrock is a marine sandstone/mudstone rock from the Purisima Formation which was deposited between about 2.5 and 11 million years ago. The type-area for this is along the Purisima Creek, a few miles south of the city of Half Moon Bay. One thing making this marine terrace different is that it is at a restraining bend of the San Gregorio Fault, where the fault path deviates substantially from a straight line to cause compression as the plates squeeze past each other, so it was pushed up by the compressive forces and now sits high above the surroundings.

The beach sand sitting on top of the bedrock is called an inter-tidal sand layer and is observed at many locations in the bluffs including within the large landslide

basin (LLB) seen in the middle of the bluff, and also along most of the ocean-side of the bluff near the tops of cliffs. This sand layer is dated to the Marine Isotope Stage 3, MIS 3, an interglacial time period about 50,000 years ago, meaning the sand was left behind when the subsequent glacial period began and the sea receded. Such dating is a specialty of Prof Blisniuk's, and she along with Alianora Walker and others dated several sedimentary layers using two different methods to establish that date. That date is later than for most previously measured marine terraces along the coast, so using two different methods that agree helps confirm it. Above the inter-tidal sand layer are several gravel layers coming predominantly from granite so many appear to be fan deposits that washed down from the foothills east of Highway 1. The bedrock of those foothills is the same granite associated with Montara Mountain. Where, exactly, the granite bedrock transitions to Purisima bedrock between the foothills and Pillar Point Bluff is an important question addressed during this study and helps in understanding the formation of Half Moon Bay.

**Fault Mapping:** The Google Earth image in Figure 14 shows a well delineated trace of the SGF crossing the mouth of Half Moon Bay. Many people also know there was at one time a clearly exposed fault in the cliff on the north end of Seal Cove beneath the first private property adjacent the east side of the Fitzgerald Reserve as shown in Figure 2, here called the Fitzgerald Fault. It is now covered by riprap, but its wide fault zone in the surf is commonly viewed by visitors. Between those two clearly observed locations, the SGF-E, the eastern trace of the SGF, (a western trace lies offshore and is not discussed here) was thought to come ashore on the south end of Pillar Point Bluff near the Mavericks parking lot, step over to the east side of the

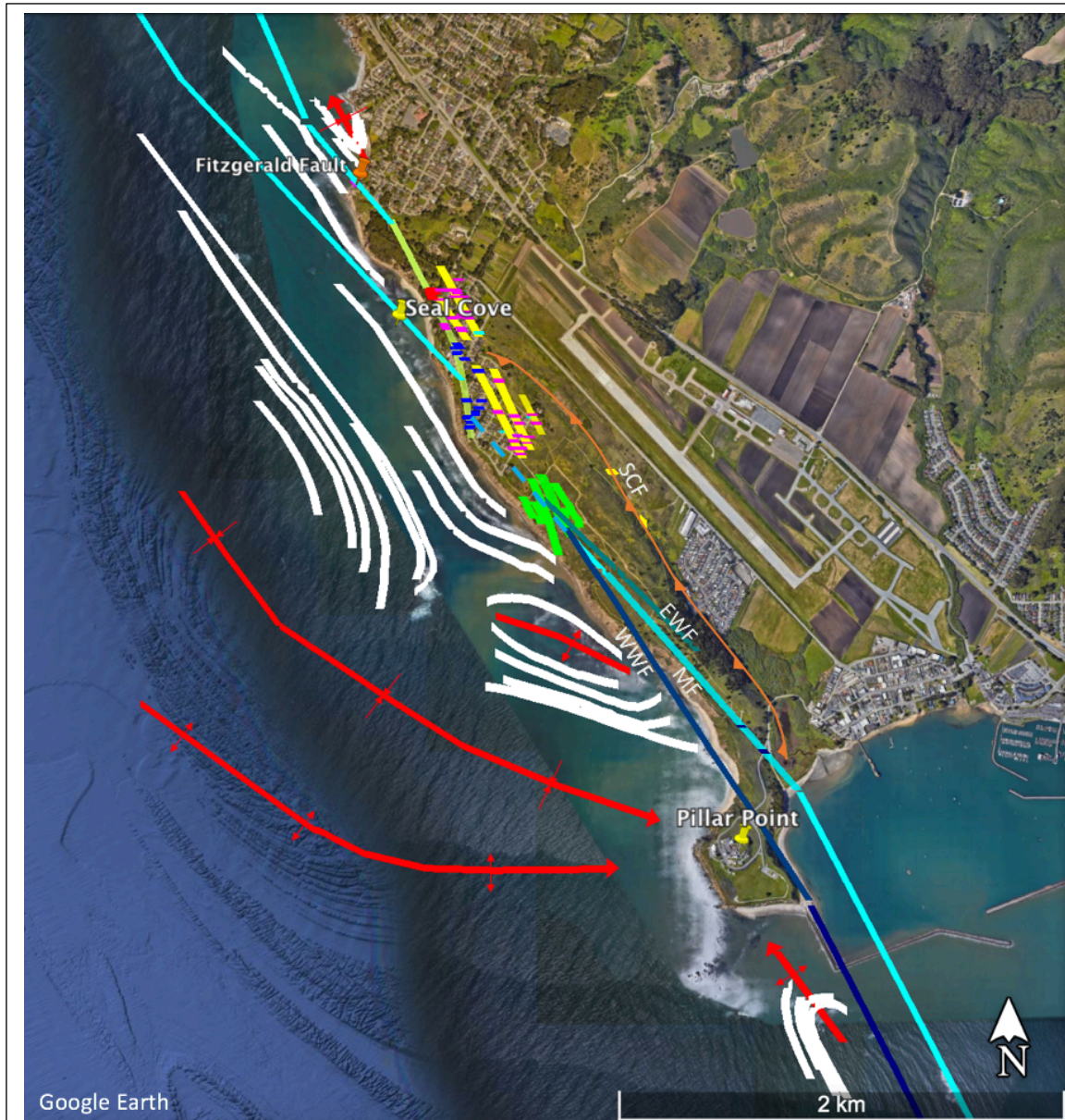


Figure 3: (4) New mapping of faults along Pillar Point Bluff. See Figure 4 in full report for descriptions.

bluff, and continue on an almost straight line along the scarp and thence on to the exposed fault. That is shown by the gold line in Figure 1 which is how it has been mapped by the USGS.

After consolidating a lot of geological consultant reports for Seal Cove and mapping stress cracks in road-beds and hillsides throughout Pillar Point Bluff, exposing and characterizing faults on the south cliff of the LLB, and collecting magnetic profiles across the bluff I have determined the main path of the strike-slip SGF-E does not actually step over to the east side of the bluff near the Mavericks parking lot, but rather continues straight up through the middle of the bluff, generally following the service road going northwest perpendicular

from West Point Road and continuing on through the center of the LLB. On the north side of that basin things become a bit more complicated and it is all mapped in Figure 3.

At one time the main fault continued straight along that path described above and went offshore along the south side of Seal Cove.

A remnant of that

fault is what causes that deep ravine between the Distillery Restaurant and a prominent hill west of it. In a bathymetry map of the seabed, as shown in Figure 4, this trace is seen to proceed offshore to the northwest and then turn more northward. Besides this earlier path that continues northwestward from Seal Cove there is also a series of faults crossing to the east starting from the north side of the LLB with at least a couple joining to exit land at the Fitzgerald Fault. These are the faults commonly exposed in trenches by geologic consultants for new developments. Of the multiple faults that participate in this crossover the currently most active fault is the

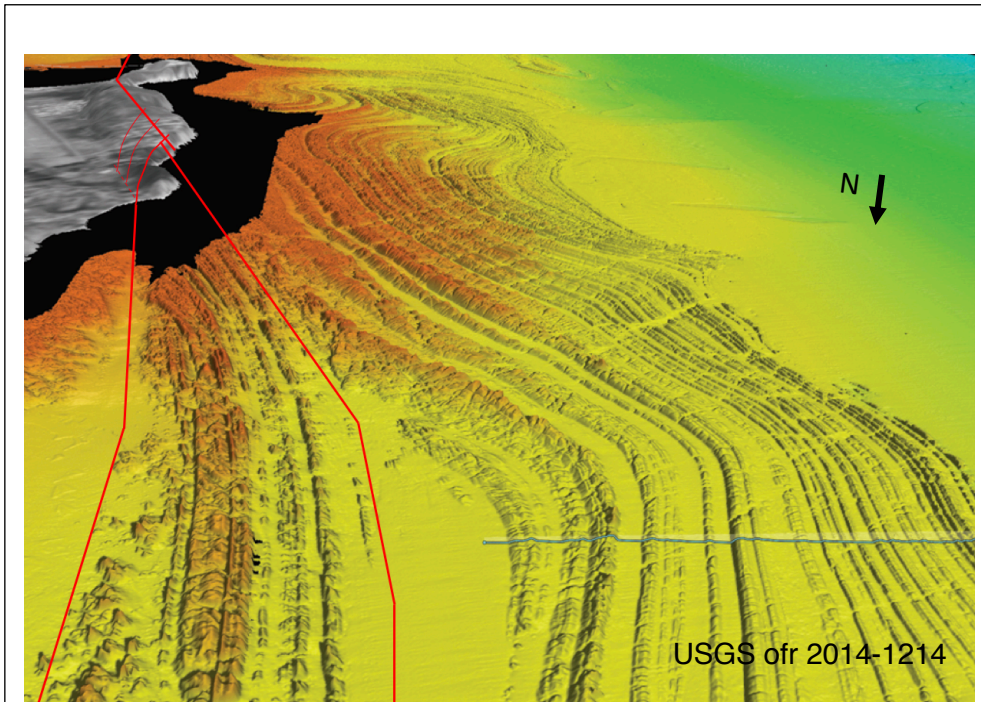


Figure 4: (7a) Two northwest proceeding fault paths in red. View looking south.

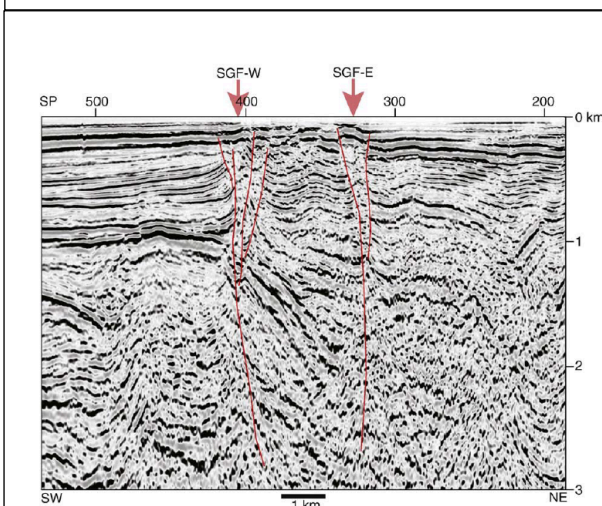


Figure 5. (7) A seismic reflection profile about 12 km northwest of Seal Cove showing the SGF-E fault has two branches that converge at depth.

“Distillery Fault”. It lies the furthest west of the identified crossover faults and its effect is seen starting at the corner of San Lucas and Ocean. It passes along the abandoned stretch of Ocean Blvd, crosses the east side of the Distillery parking lot, enters the Fitzgerald Reserve near the corner of Cypress and Ocean, passes through another well-known fault location previously identified by Simpson and others in 1997, skirts along the edge of the small Fitzgerald Bluff, and goes back out to sea through the Fitzgerald Fault. This path continues offshore almost parallel to the western fault path and the two fault components are seen in seismic profiles further north to reconnect at depth, Figure 5. The ground movement along that path previously had been thought to be “mass wasting”, basically localized land sliding due to sea cliff failures and erosion. The stress features in the roadbeds, such as seen in Figures 6 and 7, are probably well-known to many residents and to the county road department that frequently repairs them.



*Figure 6: (C1) Riedel shears in asphalt roadbed at corner of San Lucas Ave and Ocean Blvd; GPS Coordinates: 37°, 30', 54.1" N; 122°, 30', 42.6"W.*



*Figure 7: (C6) Riedel shears in asphalt roadbed on Los Banos Ave west of Park Ave; GPS Coordinates: 37°, 31', 3.1" N; 122°, 30', 43.4"W.*

They are called Riedel Shears and have a characteristic shape (en-echelon shears rotated clockwise) that indicates they record right-lateral tectonic movement. (That means when you face such a fault the tectonic plate on the other side of the fault moves to the right.) Such shears and other offsets are also seen on West Point Road near that service road mentioned above and in the service road itself up where it curves to the east. Of interest is that these shears suggest this fault may actually be creeping. That is, it may be moving slowly in the absence of an earthquake. In order to verify that, a new set of survey points on West Point Road and the service road is being monitored by Prof. John Caskey's group from SFSU.

On the south end of the bluff besides the main fault two other faults run almost parallel to it and merge with the main path near the north side of the LLB. Of these three sets of faults

the main one. MF, and the one west of it, WWF, are clearly strike-slip faults (horizontal movement), however the one on the east, EWF, has not been as clearly identified and is possibly dip-slip (vertical movement). One consultant's report of a fault near the south end of Pillar Point Bluff, the Connelly and Rubin report, found evidence of a dip-slip fault in bedrock and this looks like it may align with the EWF. This finding also suggests the fault along the prominent eastern scarp, which is very close to this dip-slip fault, is also likely dip-slip – the point made at the beginning and further supported by other data in the report.

The faults running down the middle of the bluff were exposed, and hand excavated (with a permit from the SM County Parks Dept) in the LLB so that some faults are traceable all the way from the bedrock Purisima up through the wavecut platform into the overlying sand and gravel and even up to the surface in some locations. This presented a unique opportunity to characterize this transition zone and also allowed a measurement of how the fault plunge (plunge is the deviation from perfectly horizontal) changed over time. For instance, during an early phase the mostly strike-slip fault included a small amount of vertical motion with the eastern side rising relative to the western side, but during a later phase it switched to the western side rising.

## **Movement Rate:**

One question geologists like to answer is how fast is the fault moving? Called the slip rate this is the average rate, usually in millimeters per year, the fault moves over some time frame that is long enough to have included multiple earthquakes. For the SGF various previous estimates had been in the range of 2.5 to 11 mm/yr, a larger uncertainty range than is typical. For comparison, the San Andreas Fault is measured around 20 to 35 mm/yr over its full length.

To measure a slip rate two things are needed: an offset between the two sides of the fault, at a feature called a “piercing point”, and the time over which that offset occurred. A typical example is a river that is deflected to a “Z” shape where it crosses a fault and the date when the river last was straight. In fact, the San Vicente River is almost an example of that. It flows toward the Fitzgerald Bluff, then bends northwestward as it approaches the fault and runs along the fault (past the Fitzgerald visitor center). The problem is that it empties into the ocean before forming another westward bend where it could be identified as the original continuation of the river. The length of the offset is, thus, not known except to say it is greater than about 200 m.

A better piercing point is the movement along the Distillery Fault that translated the Fitzgerald Bluff to its current location. The Fitzgerald Bluff was at one time the continuation of Pillar Point Bluff. At that time the eastern scarps of the two bluffs were assumed to have been aligned, as shown in Figure 8. Then the Distillery Fault shifted the Fitzgerald Bluff about 224 m northward to its current location. When did the Distillery Fault movement start? It would likely have been after the wavecut platform was abandoned since that platform underlies both bluffs, but exactly when is unknown. Also unknown is how much of the motion was partitioned to the Distillery Fault and how much to the western trace that goes offshore at Seal Cove.

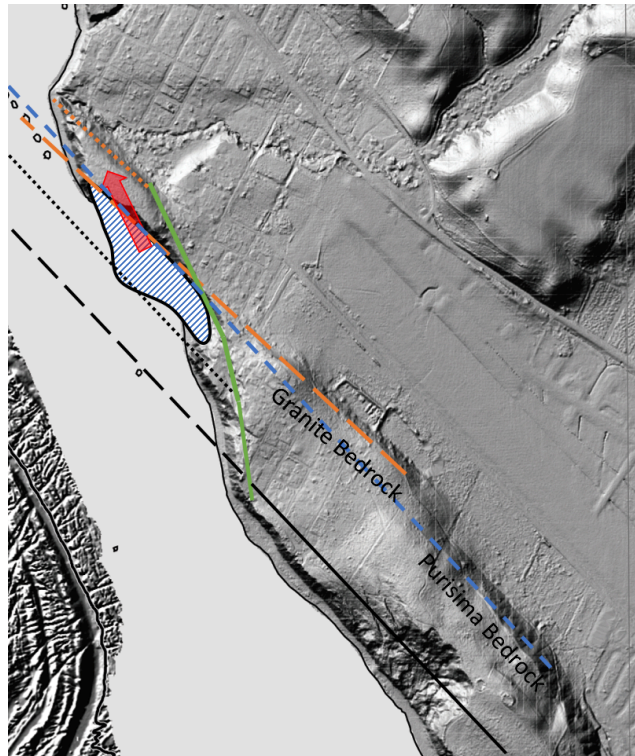


Figure 8: (64) Original position of Fitzgerald Bluff (blue cross-hatched), aligned with the eastern scarp of PPB (orange and blue dashed lines), and its translation  $317 \pm 90$  m along  $332 \pm 6^\circ$  (red arrow) along the Distillery Fault (green line) to its current location (dotted orange line). Coeval translation of NW going MF fault included (black dashed to black dotted lines).

That leaves one good piercing point, and that is what I used to measure the offset along all the faults on Pillar Point Bluff over a well-defined time frame. This method is a bit unusual and to understand it, first note that to the west of Pillar Point Bluff is a set of folded strata that have been frequently remarked on as a pristine example of geologic folding as seen in aerial photos or the bathymetry map in Figure 1. This fold structure exhibits two ridges with a valley between, namely, two anticlines separated by a syncline, and in this case the upper elevations were eroded off by sea waves. If it hadn't been eroded, it would look roughly as shown in Figure 9 or 10. A second thing to note is that the wavecut platform displayed in the south wall of the LLB, as seen in Figure 11, is tilted slightly toward the east, landward. This can be viewed from the main trail passing the LLB. When wavecut platforms are formed, they always slope slightly toward the sea about 3 degrees, but here is a wavecut platform that is now sloping landward about 4.5 degrees. To see how it rotated 7.5 degrees look at

the right side of the second fold in Fig. D9. As the western plate moves further up the restraining bend the slope gets steeper toward the landward side of the second fold. A history for the wavecut platform is then as follows: it first formed sloping seaward about 3 deg, the sea receded stopping further erosion and leaving behind a layer of sand (the platform is said to have been "abandoned"), then tectonic offset moved it along the fold while simultaneously rotating the platform landward. Measuring how far it has to go along the fold to rotate 7.5 degrees is then how far the wavecut platform moved since it was abandoned. The age of the wavecut platform abandonment is known from the dating of the sediment on top of it so with an offset and a well-defined time over which that offset occurred a slip rate can be calculated. This is what I did, with some complications due to erosion, as described in Appendix D of the report. This resulted in a surprisingly high degree of fit for the angle of tilt versus the distance along the fault, Figure 12, resulting in a quite precise offset. Combining that with the dating of the sediment produced a reliable slip rate of 6.5 mm/yr (95% confidence range of 5.2 to 8 mm/yr). One concern with this method is that it has not been used before, so it invites

skepticism. In any case, the result does tighten up the range and assigns it to a well-defined time frame and is within the range of previous estimates.

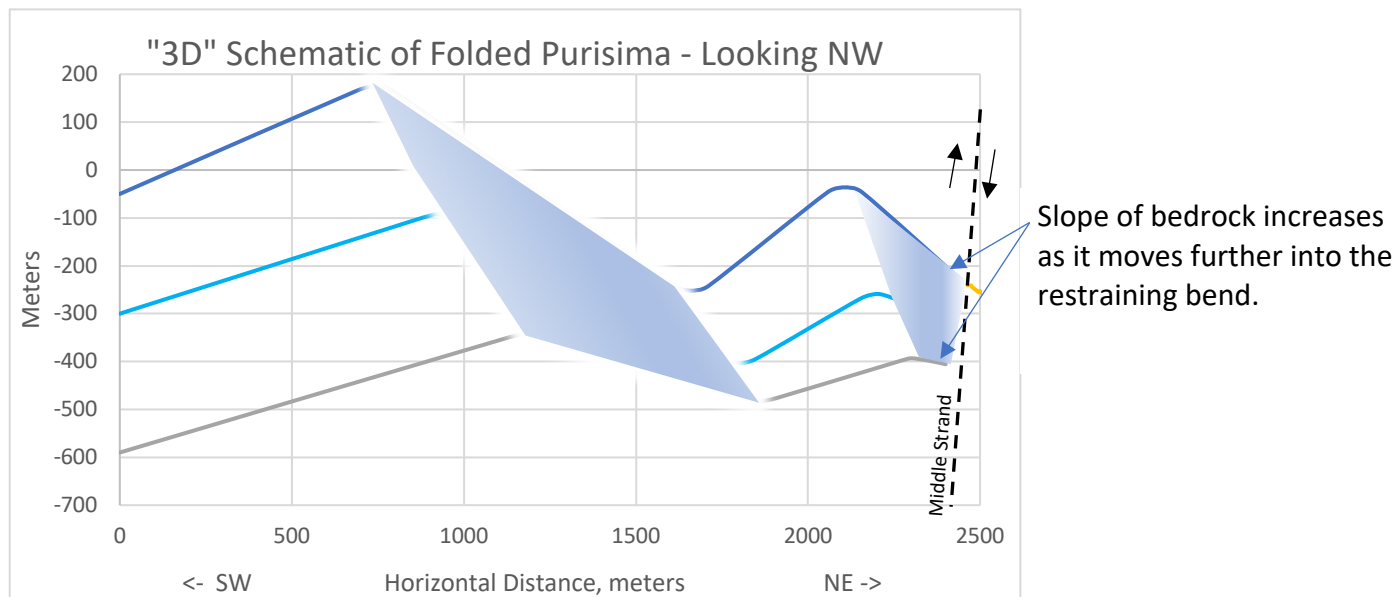


Figure 9: (D2) A schematic of the folding to illustrate the objective of the folding model; which is to obtain the change in bedrock slope as a function of distance into the restraining bend.

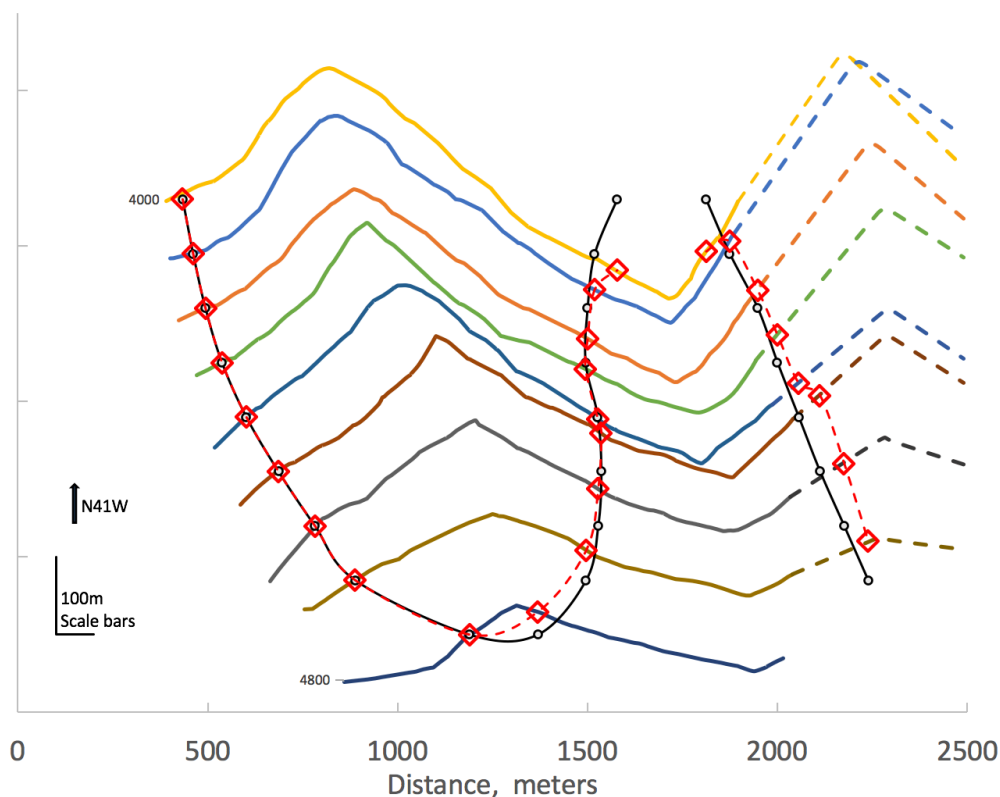


Figure 10: (D9) Reconstruction of profiles across the folds plotted in pseudo 3D including extrapolation to the near-shore anticline, dashed lines.

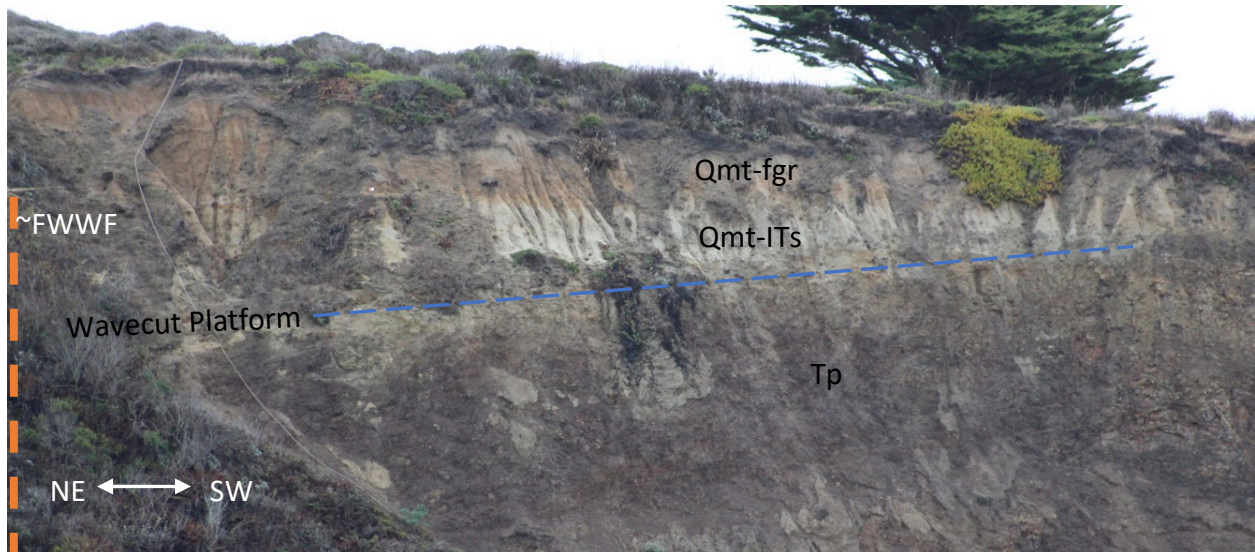


Figure 11: (55) Wavecut platform exposure on landslide scarp west of all faults, blue dashed line, the top of the greenish-grey layer. The current slope is  $4.5^\circ \pm 0.5$  NE, landward. Orange dashed line is approximate location of FWWF.

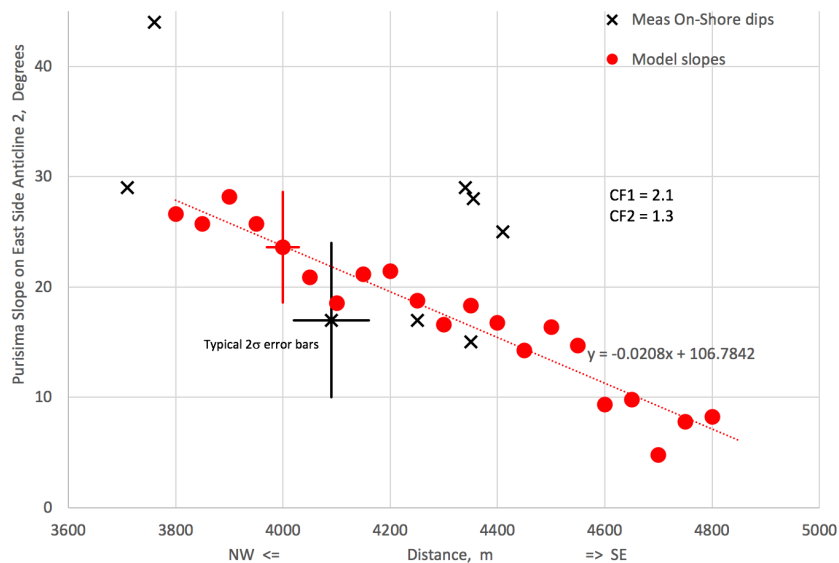


Figure 12: (D17) Purisima slope angle perpendicular to fault versus distance along the Middle Strand from the model (red circles) and black crosses are measured onshore dips.

### Formation of Half Moon Bay:

Now here is where I think things get interesting: Note all that beautiful folding offshore to the west of the SGF-E, Figure 1, the same structure used to calculate offset. That folding is a

result of compression between the Pacific plate and the fault. Newton's third law says: for every action there is an equal and opposite reaction. That implies something happens on the east side of the fault too. As explained in Appendix E of the full report that action turns out to be the formation of both Half Moon Bay (the bay, not the city) and also the Moss Beach Syncline. The implication is that Pillar Point Bluff, sitting north of Half Moon Bay but seemingly separate from it, is actually part of the reason there is a half-moon-shaped bay south of it. Plus, the Moss Beach Syncline, also called the Bathtub Syncline, well-known to local residents and college geology classes who frequently visit because it is a beautifully expressed geological fold structure, a syncline, sitting in the surf just off the end of Ellendale Street in Moss Beach, is also caused by the same mechanics.

Why is all this occurring at this location? To answer that let's back up a little. By 1971 people had started building houses in the Seal Cove area, so San Mateo County, knowing the bluffs looked potentially unstable, contracted with a geological consultant, Leighton and Associates, to investigate the Seal Cove area to get some idea of the building risks. That report, still often referenced by geological consultants working in the area, identified "lineations" from aerial photos that they interpreted as likely faults. The faults mapped in Figure 3, compiled from dozens of subsequent geological consultant's reports, follow those proposed faults very well. However, Leighton and Associates also drilled some cores down to bedrock. They found mostly sandstone, the Purisima Formation, just as expected considering the prevalence of that

sandstone in the shoreline around the bluffs. But in a few of the cores they brought up granite. That was unexpected, so they subsequently drilled a few more cores to, I believe, verify the granite and better delineate exactly where the granite began, and the sandstone left off. The finding was that a wedge of granite bedrock underlies the Seal Cove Highlands as shown in Figure 13. Not surprisingly, one of the transition lines between bedrock types was exactly along one of their "lineations", meaning that the sandstone is likely



*Figure 13: (E3) Granitic shoreline and known granitic bedrock in Seal Cove Highlands are outlined by wide pink lines. Heavy dark blue line is possible western edge of granitic bedrock.*

faulted against the granite. The granite observation and its juxtaposition with the sandstone in the Highlands does not appear to be included in subsequent geological descriptions nor in the geological reports by consultants nor in scientific papers. It's possible many, if they happened to notice it, doubted its validity or its relevance.

In Appendix E the case is made that this granite is likely an extension of the granite observable in the Moss Beach shoreline from Montara Beach to Vallemar Bluffs and over to North Point (the prominence northeast of the Moss Beach Syncline). If that's the case, then that small block of granite under the Seal Cove Highlands would be connected to the granite that is on the outer reaches of Montara Mountain.

Granite is much harder and stronger than sandstone. If a tip of a large granite block moved into the path of a fault that had been fracturing through sandstone it is likely the fault would, at least initially, skirt around the granite and continue faulting through the sandstone. That is exactly what is proposed to have occurred in the Seal Cove Highlands. That would explain why Pillar Point Bluff is a restraining bend. But not only that, the Pacific Plate pushing against that restraint, effectively pushing against Montara Mountain, applies an extensive force on the eastern plate south of the contact point and a compressive force north of it. As illustrated in Figure 14 and explained in Appendix E the extensive force formed the Half Moon Bay Syncline (causing the half-moon shaped bay), the compressive force formed the Moss Beach Syncline.

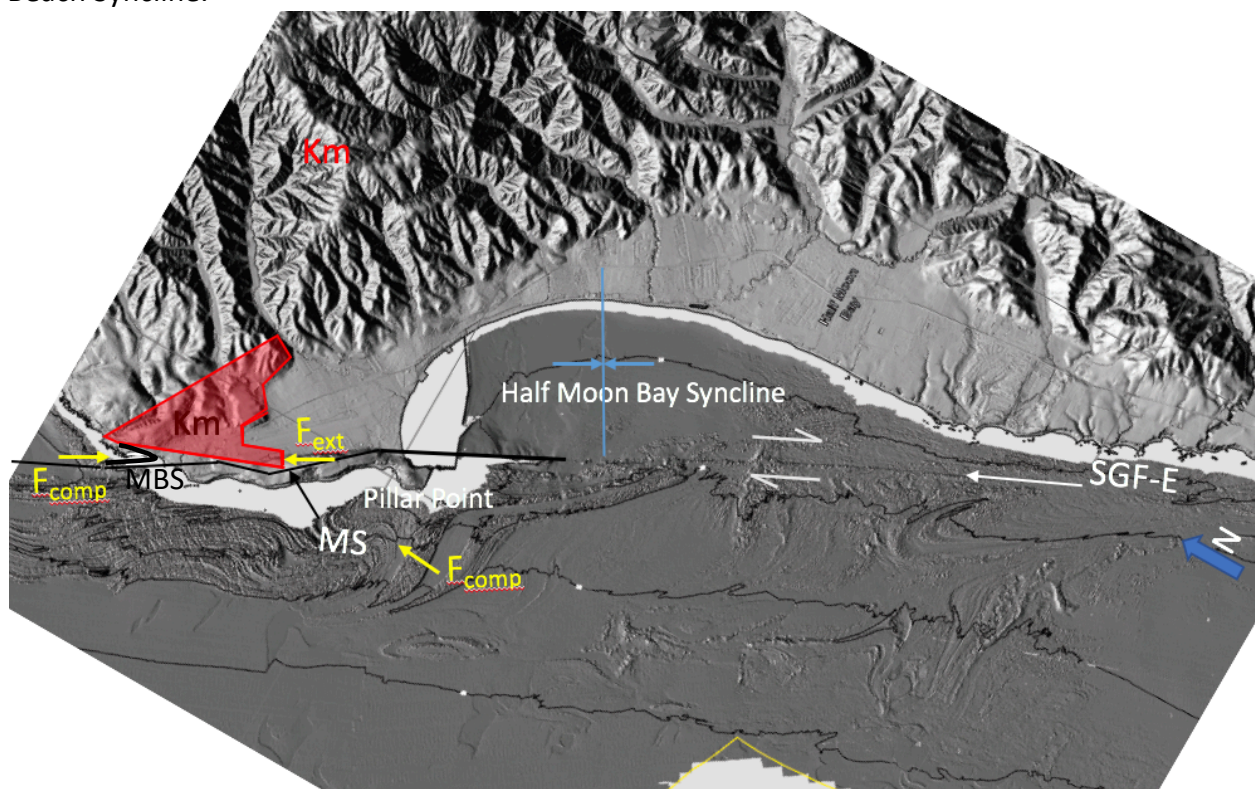


Figure 14: (E6) Schematic showing how a proposed Km (Montara granite) spur protruding into PPB produces a restraining bend that simultaneously produces compressive forces causing folding west of Pillar Point Bluff, an extensive force producing the syncline across Half Moon Bay, and a compressive force producing Moss Beach Syncline, MBS.

Profile data across Half Moon Bay in Appendix E and magnetic anomaly measurements across the likely granite/sandstone contact lines in Appendix F support this interpretation although other geophysical measurements would be helpful to further verify it. There is hope that additional resources will become available for such future measurements.

So, what started out as an enjoyable hike through Fitzgerald Reserve on the bluffs covered by those stately cypress trees above Seal Cove and noticing that a nice straight line of those trees went right over the SGF scarp (Wouldn't that make an interesting project to see if those trees have been offset by the fault, I thought) has now, after about 5 years, resulted in a much more detailed new understanding than imagined. The local geologist guru, Robert McLaughlin, retired from the USGS - everyone in the area knows and likes Bob and I learned much about him before I ever met him - found out what I was up to and was a fountain of knowledge and encouragement and connected me with many other geologists. I can't thank him enough. I was once told no-one was interested in the San Gregorio Fault, but now there are very qualified people planning to do much more detailed investigations that will yield further understanding of this fault. I look forward to learning much more and hope my investigation proves useful to future researchers.

There is a much more thorough report of these findings plus more figures and all the references at the same base web site for those willing to take on a few hundred pages of detail or just want more detail about any aspect of this summary. If you have trouble navigating to it, you can enter this address in your browser:

<https://ia601402.us.archive.org/21/items/geology-of-pillar-point-bluff/San%20Gregorio%20Fault%20Full%20Report.pdf>

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